Geographic Information Systems and Ciguatera Fish Poisoning in the Tropical Western Atlantic Region

John F Stinn, BA (1),* Donald P de Sylva, PhD (2), Lora E Fleming, MD, PhD, MPH (3), Eileen Hack, BS (4)

(1) Public Health Practice Program, Centers for Disease Control and Prevention, Atlanta, GA; (2) Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, FL; (3) NIEHS Marine and Freshwater Biomedical Sciences Center, University of Miami, Miami, FL; (4) Department of Epidemiology and Public Health, University of Miami, Miami, FL

Abstract

Little is known about the epidemiology of ciguatera fish poisoning, the most commonly reported marine toxin disease. In endemic areas and beyond, ciguatera is a seafood-borne illness that affects persons of all ages and socioeconomic groups. Integrating an existing ciguatera database into a geographic information system (GIS) will give researchers new insight into the epidemiology of ciguatera and allow linkage between disparate epidemiological and oceanographic datasets. A voluntary Ciguatera Hotline has collected data from 1977–1998 in the endemic ciguatera area of South Florida. Descriptional statistics and spatial trends of ciguatera cases and the fish sources were examined using ArcView GIS software. A total of 777 cases, 442 on record, with 304 index cases were analyzed from the database. Cases were distributed geographically throughout Miami-Dade County, Florida. A high concordance was shown between the location of ciguatoxic fish and specific coral reef areas in the Caribbean. Using GIS in the future may help prevent disease by pinpointing ciguatera hotspots and facilitating the exploration of possible etiologic relationships between oceanographic and anthropogenic changes in the sources of ciguatera.

Keywords: ciguatera, marine toxin diseases, tropical medicine, Caribbean region

Introduction

Ciguatera is the most frequently reported seafood-related illness in the world, affecting up to 500,000 people per year worldwide (1). The illness is caused by the consumption of coral reef fishes contaminated with a group of natural toxins produced by minute phytoplankton known as dinoflagellates. These toxins are bio-concentrated through the food chain such that humans consuming large reef fish (such as barracuda, grouper, and snapper) are the ultimate predators and receive the highest doses of toxins. The most important of the ciguatera toxins, ciguatoxin, causes a blockage of sodium channels throughout the nervous system; ultimately, this neurological blockade manifests as a multitude of symptoms, affecting numerous bodily functions (2). Ciguatoxin and the other marine toxins are heat/acid-stable; therefore normal food preparation does not detect or eliminate them. Furthermore, these toxins are some of the most highly toxic natural substances; ciguatoxin is toxic to humans in picogram doses (3). The

* John Stinn, Centers for Disease Control and Prevention, Public Health Practice Program Office, 4770 Buford Hwy, MS-39, Atlanta, GA 30341 USA; (p) 770-488-2449; (f) 770-488-2489; E-mail: zjj8@cdc.gov

symptoms of ciguatera may persist in humans from a few days to up to several months or even years, depending on the size of the fish, the size of the contaminated portion, and the seafood consumption history of the victim (4).

Ciguatera is the predominant fish poisoning in the endemic tropical regions of the Pacific and the Caribbean (5). The social and economic impacts of ciguatera in endemic regions are the avoidance of the consumption and sale of seafood. For example, Tahiti, the most populated island of French Polynesia (135,000 inhabitants), loses an estimated US $1 million annually due to banned reef fish sales (6). With increasing international travel and trade as well as increasing fish consumption, ciguatera is being imported to traditionally non-endemic areas (7). The medical costs and lost wages for ciguatera victims can be quite high, especially in non-endemic areas where diagnosis is often delayed due to non-recognition by victims and their healthcare providers. For example, in the non-endemic region of Canada, these costs have been estimated between US $1,850 and US $8,950 per case (8).

The Centers for Disease Control and Prevention (CDC) estimate that fewer than 2–10% of ciguatera cases are actually reported in the United States (9). Many biases contribute to the underreporting of ciguatera. First, there are no easily available inexpensive tests for the ciguatoxic fish or human victims. Second, although ciguatera is a reportable disease, many healthcare providers do not recognize, diagnose, or report ciguatera, especially in non-endemic areas. Third, there is a lack of knowledge in the recreational fishing community about ciguatera and possible prevention measures. Finally, there is a desire in the restaurant and commercial fishing industries to suppress publicity of ciguatera as a threat to seafood consumers (10,11,12). Given the plethora of underreporting issues, large comprehensive ciguatera databases such as the one used in this study are rare (1,9,11,13). Therefore, the epidemiology of ciguatera is still in its infancy.

Expanding ciguatera epidemiological investigations with technology such as geographic information systems (GIS) may help researchers gain new insight. GIS can be used to collect, check, integrate, and analyze information related to the earth's surface, allowing for the integration of non-traditional datasets (14). The digital nature of GIS software allows for the data and analyses to be easily updated, transferred, manipulated, and displayed (15). In the case of ciguatera, GIS could be used to evaluate possible associations between epidemiologic and oceanographic data. By using GIS mapping capabilities, the distribution and trends of ciguatera cases in time and space can be evaluated to increase the knowledge of ciguatera epidemiology. Furthermore, the source of the ciguatera could be traced from the human cases to the contaminated fish and then back to the ciguatoxic coral reef. This in turn could lead to possible primary prevention activities such as ciguatoxic reef postings, thus discouraging fishing and further seafood consumption in known contaminated areas.

The following study is an analysis of a 20-year database of self-reported ciguatera cases in South Florida, using GIS to evaluate both epidemiologic and oceanographic data.

Methods

Since 1977, researchers at the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS) have attempted to inform the South Florida public, the seafood industry, and the medical profession about ciguatera (16). Press releases, radio and television interviews, and magazine articles have been used for outreach and education about tropical fish poisoning. A voluntary Ciguatera Telephone Hotline, networked with the local medical and public health communities, was established. A standardized questionnaire was implemented. For over 20 years, investigators at RSMAS have received letters and telephone calls from victims, healthcare providers, and concerned seafood customers, primarily from South Florida and the Caribbean. The resulting database, "Ciguafile" (17), represents one of the largest and oldest collections of ciguatera cases in the world, despite the multitude of underreporting biases.

The Ciguafile database consists of ciguatera cases from 1977 to 1998. Ciguatera victims and healthcare providers voluntarily reported these cases. Case demographics were recorded, including the age, residence, gender, symptomatology, progression of the illness, species and weight of the fish involved in each outbreak, location of the capture, date of the capture, and other pertinent information. Race-ethnic and socioeconomic class data were not collected in this database. Data concerning how many additional people consumed the same fish, if those people became sick, and where the fish was procured were also collected. These data were stored in a Microsoft Excel spreadsheet. The subjects' addresses in Miami-Dade County (Miami, FL) were geocoded and referenced with a South Florida street map using ArcView GIS (ESRI, Redlands, CA).

For those ciguatoxic fish captures with exact data on capture location available, the latitude and longitude were converted to decimal-degree units and displayed over a map of the Caribbean region using ArcView GIS. In addition, ciguatoxic fish captures in the Caribbean documented with sufficient detail in the historical literature were also added to the database. Documented coral reefs of the region were also displayed using historical data on coral reef location (18,19).

Nearest-neighbor analyses were performed on both the residential data and capture location data. The nearest-neighbor statistic (R) is based on the comparison of observed spatial distribution with what one would expect if the distribution were completely random. The statistic has a range of 0 to 2.15. An R-value of zero indicates a completely clustered pattern, a value of 1 indicates a random distribution, and R=2 or greater corresponds with a completely uniform (even) distribution (20).

To evaluate the hypothesis that ciguatera is derived from the consumption of fish associated with coral reefs, the following analyses were performed. First the capture location of each fish was referenced to the distance from the nearest coral reef. Then, based on data for the home ranges of individual fish species, a maximum distance of 1 mile of range from each known coral reef was selected (21). Nearest-neighbor analyses were performed, and the relative spatial density of ciguatoxic fish captures was determined.

Results

There were 442 cases in the Ciguafile database, with a total of 777 reported cases (these included additional cases reportedly sharing the same fish). The mean age of the database cases was 44.7 ±15 years (range 4 months to 87 years); most (53.2%) cases were female. Victims reported a multitude of symptoms, most commonly paresthesia and acute gastrointestinal disorders. A comparison of the symptoms reported in Ciguafile and other previously published ciguatera case registries can be seen in Table 1 (1,9,22–27).

Many cases were involved in cluster outbreaks, where the sharing of one fish was responsible for multiple cases. Based on the available information, 304 ciguatoxic clusters were recorded in the database. Ciguatera was more likely to be present in disease clusters with an average of 2.36 persons/cluster. Within the 304 cluster outbreaks, there was an attack rate of 87.5% per cluster of those who reportedly consumed a toxic fish and who experienced ciguatera symptoms.

To evaluate the geographic distribution by residence at the time of illness, cases from 1978 to 1981 within Miami-Dade County, a ciguatera endemic region, were analyzed (Figure 1). Of the 304 index cases, 169 occurred in Miami-Dade County, with 102 (60.4% of Miami-Dade County cases) of these cases occurring during the specified time period. A nearest-neighbor analysis was performed in an attempt to show a random distribution of cases in the county. However, despite various attempts to adjust for population density and lack of habitability (e.g., airports, Everglades, and ocean areas), the R-value was 0.10, indicating a strong clustering pattern. Nevertheless, the clustering pattern closely followed densely populated roadways that pass through highly varied race-ethnic neighborhoods in Miami-Dade County.

The causative fish were acquired through individual fishing (31.6% of the cases), buying from fishermen, stores, or restaurants (64.1%), or as gifts (4.3%). Overall, the most frequently implicated culprits in the outbreaks were groupers (47.1%), snappers (30.7%), barracudas (9.6%), kingfish (6.1%), jacks (5.7%), and dolphin fish (4.6%). Because the identification of restaurant-acquired fish type can be faulty (28), only the fish types and weights of the fish reported by individual fishermen were examined. The most commonly reported fishes leading to outbreaks reported from fishermen were barracudas (average size 10.6 lb; range 4–22 lb); kingfish (37.2; 6.5–100); black groupers (51.3; 26–73); amberjacks (26.4; 7–47); red snappers (9.8; 3.5–17.5); and hog snappers (4.6; 2–10).

There were 50 ciguatoxic fish captures with location data; 111 ciguatoxic captures in the Caribbean were also documented in the historical literature in sufficient detail to allow for GIS mapping (4,29). Of the 50 Ciguafile captures, 43 (86%) occurred in the region between the Florida Keys and the Bahamian chain. The historic captures were spread throughout the Caribbean. When examining the 161 confirmed fish captures as a whole, some areas of the Caribbean reported ciguatera outbreaks much more frequently than others, especially Puerto Rico and the neighboring US and British Virgin Islands (Figure 2). Furthermore, the fish captures were strongly clustered, as confirmed by the nearest-neighbor tests with $R<0.02$, using the Caribbean Sea and Gulf of Mexico as the reference region. This clustering pattern closely followed the line of coral reefs adjacent to the small island nations of the Windward and Leeward Islands.

Conclusions

This study is an analysis of a 20-year database of self-reported ciguatera cases in South Florida and uses GIS to evaluate both the epidemiologic and oceanographic data. It illustrates that ciguatera is a disease that occurs in clusters and affects persons of all ages. The data also reflect that ciguatera affects individuals in different ways

Table 1 Reported Frequency of Clinical Symptoms of Ciguatera

	Region of Study Source of Data (Reference #) Number of Cases (n)									
Symptoms (reported by % frequency)	**Caribbean (17) (n=442)**	**Caribbean (24) (n=57)**	**Caribbean (22) (n=47)**	**Caribbean (9) (n=129)**	**Caribbean (25) (n=16)**	**Caribbean (23) (n=80)**	**Caribbean (27) (n=6)**	**South Pacific Islands (26) (n=12,890)**	**Western Pacific (Australia) (1) (n=167)**	**South Pacific Isles (11) (n=3,009)**
Gastrointestinal										
Diarrhea	78.7	77	81	76	56	83	66	72.6	49	70.6
Vomiting	42.5	37	40	68	69	69	66	38.8	50	37.5
Nausea		82				69	100	43.5	50	42.9
Abdominal pain	64.5	58	30		75	74	66	42.5	29	46.3
Neurological										
Arthralgia	78.7	75	34		31	60		85.9	29	85.7
Myalgia	79.0	75	34	86	94	56		85.3	38	81.5
Extremity paresthesia	81.0	79		71	38	36	50	89.0	82	89.2
Circumoral paresthesia	69.5	79	38	54	38	38	33	88.1	82	89.1
Temperature reversal	64.3	77	23		50	48	16	87.2	65	87.6
Headache		56	45	47	50	39		59.6	25	59.2
Dizziness/vertigo	50.0			47	56	33	16			42.3
Weakness		84		30	94	65.4		60.0	70	60.0
Chills/sweating			36	24				59.6		59.0
Other										
Dysuria	25.0				31			12.6		18.7
Pruritus	77.0		66	48	100	45	66	44.0	5	44.9
Dental pain or “looseness”	32.1	23	13		19	11		20.7		24.8
Dyspnea								12.1		16.1
Skin rash	32.1				31					20.5

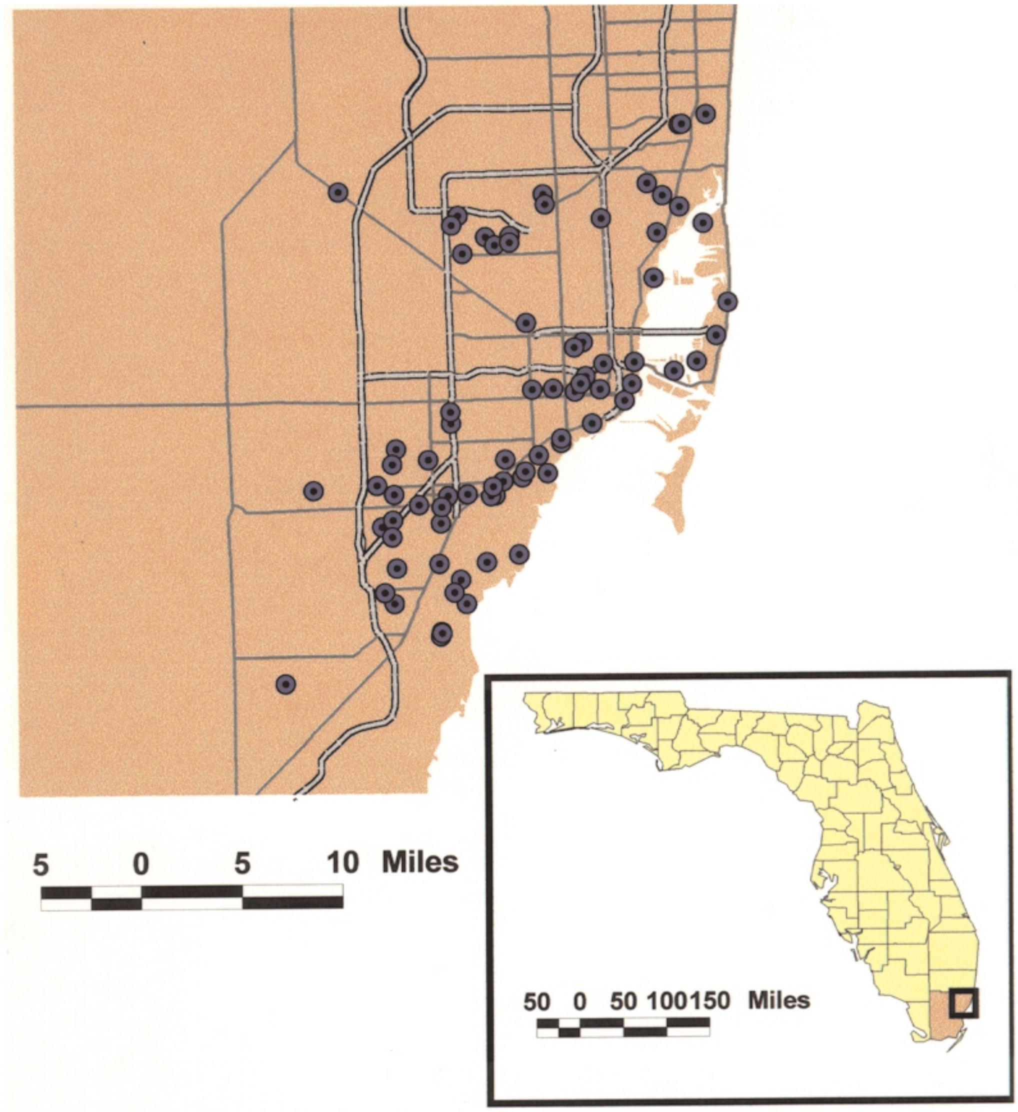

Figure 1 Ciguatera cases, Miami-Dade County, FL, 1978–1981 (17).

symptomatically. Very few people reported all the possible symptoms, making it even more difficult for accurate diagnosis on the health care provider's part.

The Ciguafile is a passive collection database. It relies on the referral and reporting by physicians and ciguatera cases with actual knowledge of the Ciguatera Hotline telephone number. This can lead to obvious reporting bias. As such, no reliable incidence rates can be generated for South Florida from these data. A previous study in Miami-Dade County indicated that the incidence rate of ciguatera was at least 5 cases/10,000 people/year (9). In the neighboring Caribbean and other tropical regions, the rates are even higher, with estimates of over 100 cases/10,000 people/year on some tropical islands (30).

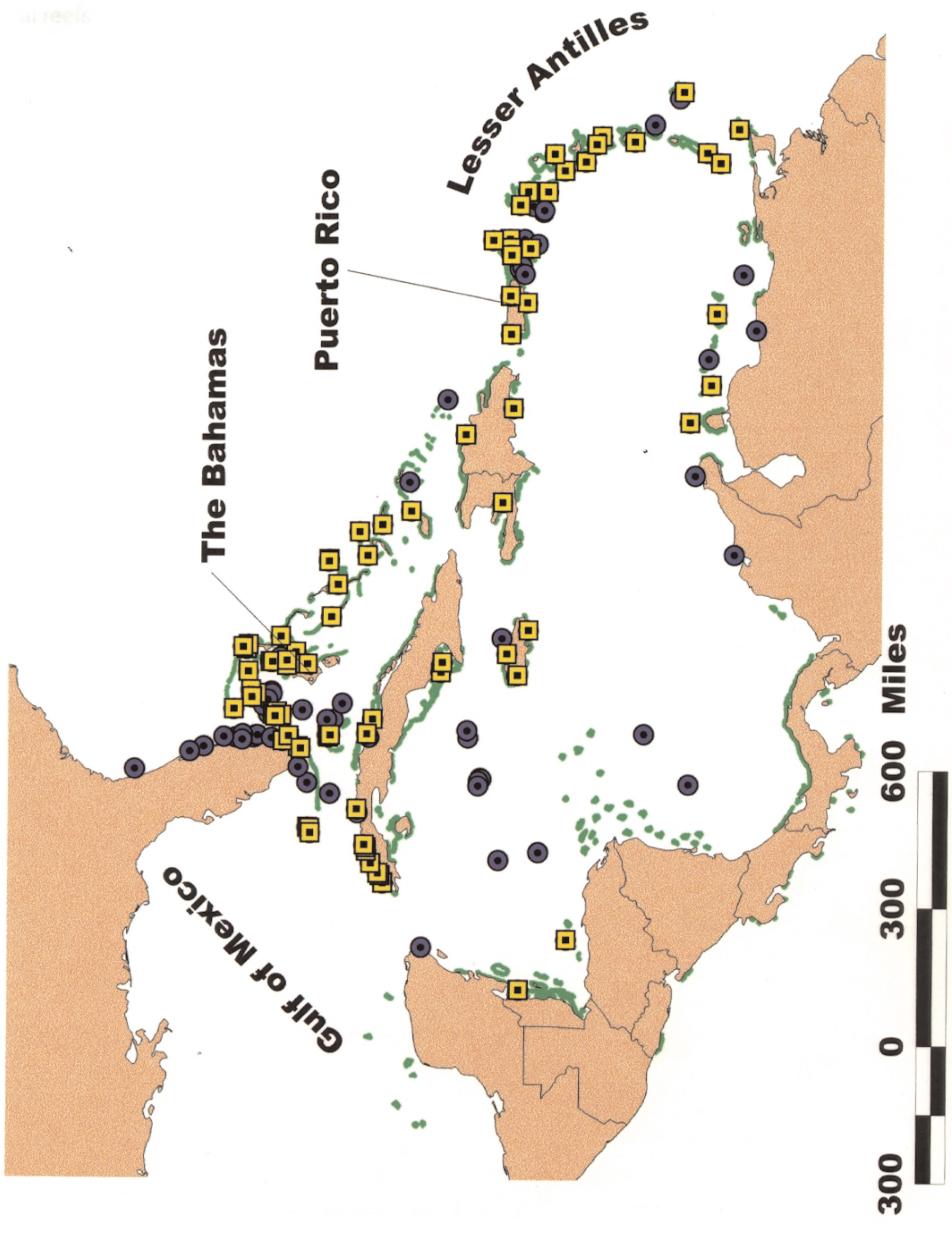

Figure 2 Ciguatoxic fish captures, greater Caribbean, 1900–1998 (4,17,29).

The clustering pattern of residences noted in the geographic mapping of cases in Miami-Dade County occurred along a major roadway throughout the county that crosses race-ethnic and socioeconomic lines in its course. Although precise data were not collected, this suggests that ciguatera affects all persons regardless of race-ethnic group and socioeconomic class. In addition, the non-random spatial clustering in Miami-Dade County may reflect the proximity to and locations of seafood restaurants or fish markets because the most implicated fish were acquired in markets and restaurants.

Another issue is that the capture location data reported from Ciguafile were neither accurate nor precise. This is an issue for the use of GIS (15). Many of the subjects reported incidents weeks or even months after consumption. Aside from two Ciguafile cluster reports with precise global positioning system (GPS) coordinates, fish capture locations were reported in vague terms such as "two miles west of Great Isaac's Light" or "just off the northeast point of Grand Bahama Island." Therefore, the data from this study are good for identifying general ciguatera hotspots, not citing specific individual reefs that may or not be safe. In the future, more accurate capture data could allow for the identification and posting of individual coral reefs. The measure could lead not only to primary prevention of ciguatera (important due to the lack of quick and inexpensive testing) (31), but possibly to ecological relief for over-fished coral reefs (4).

Analysis of the fish capture locations showed an association with specific coral reefs. Changes in the reef environment, however, may inhibit accurate analysis. Overfishing may temporarily eliminate the possibility of ciguatera. It cannot be determined if the environment is not conducive to the disease or if it is simply because the reefs have been overfished. Some biologists feel the fish that are captured in certain overfished or overexploited waters are usually too young and small to be contaminated with potent amounts of ciguatoxin (32). Should the reef communities rebound, the disease may manifest itself again.

Spatial density analysis revealed hotspots near Puerto Rico and the Bahamas, indicating the potential to identify ciguatoxic reefs in these areas (Figure 3). There are, however, severe problems with this type of analysis. Spatial density does not account for disparity in captures over time. Given the multitude of underreporting concerns against ciguatera, gaining these data may be difficult. Spatial density analysis ignores the theoretical possibility of migrating fish from a toxic reef to a safe reef. Nevertheless, the trend of ciguatoxic captures occurring along the reefs, and in certain areas more than others, cannot be ignored and must be investigated.

State and county health departments are increasingly adding GIS to their disease reporting and surveillance systems, and are collaborating with environmental departments when analyzing exposures to dangerous substances. GIS allows for linkages and analysis of different databases, such as oceanographic and epidemiologic, to explore complicated environmental diseases such as ciguatera. Also, the real-time editing capabilities and transferability characteristics of GIS databases may allow for better education and awareness of ciguatera, particularly among health officials in non-endemic regions. This may help overcome many of the historic educational and diagnostic biases against ciguatera. Furthermore, with the advent and affordability of GPS technology, most commercial and recreational fishermen can more accurately record fish capture locations. True ciguatoxic hotspots may soon be found and primary prevention initiated.

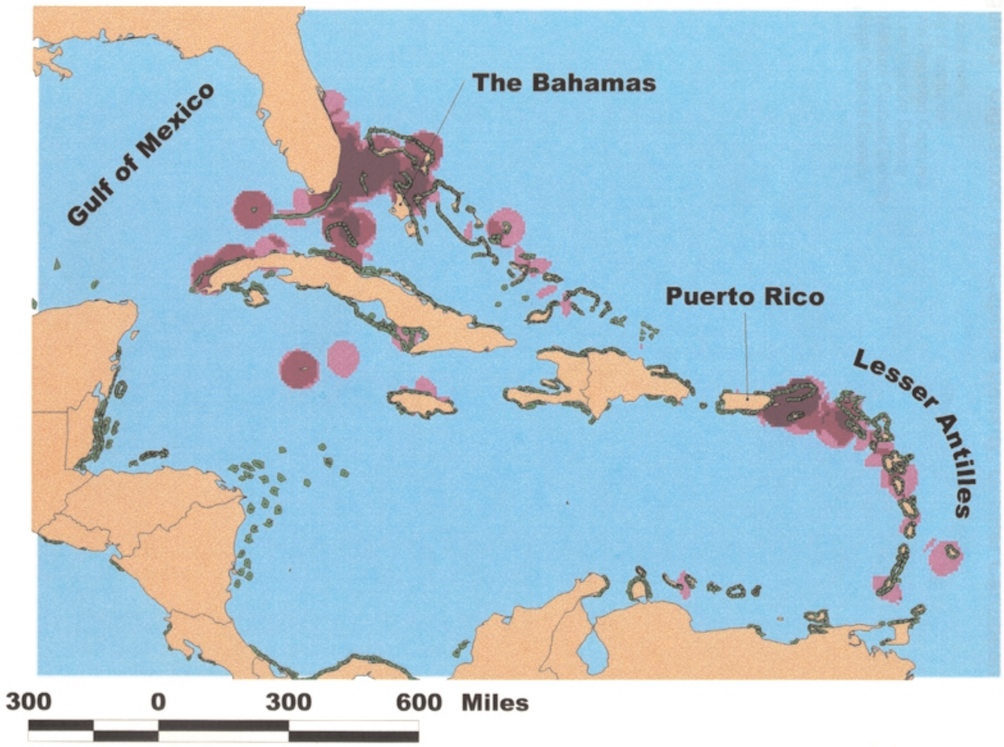

Figure 3 Ciguatoxic fish capture density, greater Caribbean, 1900–1998 (4,17,29).

In the future, GIS could be applied to the micro-marine environment, allowing scientists a new means of studying the ecology involved in ciguatera. The fishes associated with ciguatera have been known for decades (33). In 1980, researchers identified *Gambierdiscus toxicus* as the dinoflagellate most responsible for producing ciguatoxins (34). Much of the life history of *G. toxicus* has been described (35). Despite these facts, researchers continue to be baffled as to why different fishes from the same area may or may not be ciguatoxic and why certain species are poisonous on one reef but not another (36). Furthermore, it is possible that global change, coral bleaching, and anthropogenic effects on coral reef ecology may lead to further changes in the incidence of ciguatoxic reefs. The modeling and statistical capabilities of GIS may allow the biotic and abiotic attributes of contaminated reefs to be investigated in ways that were too expensive or difficult to conceptualize in prior research.

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